Bead Pull Measurement and Sensitiveness Analysis of W-Band Muffin Tin WBAND-000

Rolf Merte
Technical University Berlin
Department of Electrical Engineering
Institute of Theory of Electricity
D-10587 Berlin
merte@tetibm1.ee.tu-berlin.de

This paper is a part of a group of papers [1-3] around the first SLAC W-Band structure WBAND-000

Abstract
This Paper presents a report over RF measurements of a W-Band planar accelerating structure (WBAND-000). Shown are the results of a non resonant bead pull measurement, a transmission and a reflection measurement. Further the results of different sensitiveness analysis. The first RF measurements of this structure are presented in [3]. The measurement apparatus is explained in [1].

I. Fiber - Bead Performance

We have a lot of possibilities to do a bead pull measurement and a lot of problems appear. For perturbation measurements a perturbation, the bead, is necessary. This bead needs to be mounted on something. This something, called the support, is unfortunately a perturbation by itself. So one must endeavor to keep that inevitable second perturbation as small as possible. So, a small thread (few μm) is needed which has a diameter of less than 30 micrometer. Generally it is not easy to find the right support for beads in the W-Band, because everything is very tiny. A simple solution was to use stuff from medical applications, like very thin threads, so called fibers or sutures, for sensible eye operation with a diameter of 30 μm to 50 μm and an unknown dielectric constant.

However, this is that what we use at this time. The bead, actually, should be a metallic body which can be mounted on the fiber with different spatter technologies. At this time such a configuration was not available, so we used a simple knot as a bead, see figure 1. It is not the ultima ratio, but it works! The fiber with the knot has to be straight, without bends, curves and edges on it, when pulling through the structure. We used simple paper clips [4] as weights on both ends until we had enough tension and the fiber was straight. Figure 2.a and 2.b show a picture of the measurement. You can see the structure with
fiber inside and the paper clips as weights on both fiber ends. For the measurement the input port is
connected with the apparatus and the output port is connected with a termination. The whole
measurement set up is shown in figure 3.

**FIGURE 1.** The bead is a simple knot in the fiber.

**FIGURE 2.a / 2.b.** Part of the measurement set up, structure with fiber and weights.
II. Non resonant bead pull measurement

As said the fiber is a perturbation by itself and causes reflection. We speak of an offset that we measure. For each measured data we have to remove this offset. This is an easy subtraction. Figure 4 shows how we do this. On the left hand is the original measured data and on the right hand is the data after removing the offset. The offset is not very large because the used fiber was very thin. The red arrow is the offset vector which has to be removed from all data points.
FIGURE 4.a / b. How to remove the offset.

FIGURE 5. Amplitude of measured $S_{11}$ parameter, with fiber inside the structure.
III. Determined modes

Figure 4-5 show the result of a frequency scan for the $S_{11}$ parameter. For this frequency scan there was a fiber without a bead inside the structure. If we look at the chart, we can see different frequencies where modes are propagated (it is indicated with circles) with a very low reflection. In this chapter we try to allocate these modes. One aim of this analysis is to determine these modes, especially we want to see if the mode around the design frequency of 91.392 GHz, this is mode #3, is identical with the $2\pi/3$-mode. For this we have to determine the frequency of each unknown mode. The next step is to adjust this frequency and to do a bead pull measurement. If we look at the minima and the concerning phase, we can see that it is difficult to decide which frequency we should take, because it is not a single peak, it is like a band if we zoom it (see chapter V.). After a frequency with best eye ball fit is chosen, we have to remove the offset, caused through the fiber, of all data like it is shown in figure 4. The information we get is printed in a polar chart, because this kind of exhibition is fine for an analysis. We simply look at the phase shift over the number of cells and determine the mode. Figure 7-13 show the polar chart of the local minima of figure 5. The results are presented in table 1. It is difficult to interpret the figure 7, but together with the original data and the chart of the magnitude and phase it is easy to see that this is the 0-mode. However, figures 11-12 are difficult to allocate, figure 13 can not be interpreted. It is a nosy signal, in which we can not see anything. Unfortunately it seems that there no $2\pi/3$-mode propagates with a low reflection through the structure
FIGURE 7. Polar chart of mode # 1

FIGURE 8. Polar chart of mode # 2

f = 89.887 GHz (file BP61)

f = 90.506 GHz (file BP62)

f = 91.161 GHz (file BP60)

f = 91.510 GHz (file BP64)

FIGURE 9. Polar chart of mode # 3

FIGURE 10. Polar chart of mode # 4
**FIGURE 11.** Polar chart of mode # 5

**FIGURE 12.** Polar chart of mode # 6

**FIGURE 13.** Polar chart of mode # 7
<table>
<thead>
<tr>
<th>Mode # in figure 5</th>
<th>Frequency in GHz</th>
<th>Determined mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>89.887</td>
<td>0 - Mode</td>
</tr>
<tr>
<td>2</td>
<td>90.506</td>
<td>$\pi/3$ - Mode</td>
</tr>
<tr>
<td>3</td>
<td>91.161</td>
<td>$5\pi/6$ - Mode</td>
</tr>
<tr>
<td>4</td>
<td>91.510</td>
<td>$\pi$ - Mode</td>
</tr>
<tr>
<td>5</td>
<td>92.422</td>
<td>$11\pi/6$ - Mode</td>
</tr>
<tr>
<td>6</td>
<td>93.357</td>
<td>?</td>
</tr>
<tr>
<td>7</td>
<td>94.150</td>
<td>?</td>
</tr>
</tbody>
</table>

**TABLE 1.** List of determined modes.
IV. Frequency sensitiveness

In section III it is mentioned that it is not easy to determine the frequency of a mode, because after zooming the area around the peak it looks very flat. So another analysis tries to determine how sensitive such an area is around a peak. This means we do different bead pulls with different frequencies close to the best eye ball fit frequency and see what is going on. Figure 14 shows the result of this analysis. The shape of each diagram is in principle identical, we have the same amplitude but an phase offset of 8 degree per run.

It seems that the choice of a frequency is not very sensitive. So we can live with the best eye ball fit chosen frequency which was 91.161 GHz.

Figure 14. Polar chart of a comparison of bead pulls with different frequencies around mode #3.
V. Fiber position displacement

The next point which has to be figured out is how sensitive is the alignment procedure of the fiber inside the structure. So do we need to pay attention for exactly aligned fiber or is it all the same? For this we fixed the frequency at 91.161 GHz which was the best eye ball fit chosen frequency, see section III and good enough as determined in section IV. At this frequency we do different bead pulls at different positions. So we move the fiber in a horizontal and vertical direction. What can we see? One point is that we simulate a displacement like we get after a not perfect alignment procedure. So we can see how sensitive this set up is in reality. In case it is sensitive, we can see how the field distribution is close to the center line. Actually the aim of a bead pull measurement is to determine the field in the structure, but for this we need the shape factor of the bead which is unfortunately unknown at this time, but maybe we can use this data later. Figure 15 shows the aperture with different fiber positions where a bead pull measurement was done. In table 2 the relative coordinates in μm of the different fiber positions related to position 1, are shown. With respect to the field pattern, the vertical displacement should not be so sensitive. Otherwise it is the best to throw away the structure.

The results of this analysis are shown in figures 16-19. Figures 16 and 17 show the magnitude and phase of the measured signal for different horizontal displaced fiber positions. Figures 18 and 19 show the magnitude and phase of the measured signal for different vertical displaced fiber positions.

<table>
<thead>
<tr>
<th>Position #</th>
<th>horizontal (μm)</th>
<th>vertical (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>30</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>-10</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>-30</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>-10</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>-30</td>
</tr>
<tr>
<td>8</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>9</td>
<td>0</td>
<td>-30</td>
</tr>
</tbody>
</table>

**TABLE 2.** Coordinates for figure 15 in μm of different fiber positions.

**FIGURE 15.** Definition of different fiber positions in the aperture.
FIGURE 16. Magnitude of measured signal for different fiber positions (horizontal displacement).

FIGURE 17. Phase of measured signal for different fiber positions (horizontal displacement).
FIGURE 18. Magnitude of measured signal for different fiber positions (vertical displacement).

FIGURE 19. Phase of measured signal for different fiber positions (vertical displacement).
VI. Vibration sensitiveness

The fourth point is to see how vibration sensitive is the measurement. We don’t simulate an earth quake, but walking people around the apparatus. Figure 20-22 show the results of this test. As you can see, is the amplitude not sensitive, the measured signals are identical. The phase shown in figure 21 is more sensitive, as expected. The major question now is, is that important ? Do we need a vibration absorbing table to get the job done correctly ? I guess no! The reason for the vibration is not a vibrating fiber, it is more the tension which is transmitted from the apparatus (the devices) to the structure via the wave guides.

If you take a look at figure 3 you can see in middle of the picture a wave guide connection from structure to a coupler via two wave guide bends. The apparatus with couplers etc. is fixed, it is stationary. The structure is mounted on a translation table. This table is used to move and displace the fiber position. Also the goniometer and rotation table, which are used to adjust the fiber correctly, is mounted on this table. This means that every adjusting or movement is transmitted via wave guide to the fixed couplers. There is a high tension on this guides. And that is the critical area of the whole setup. We could avoid this by mounting the left side in figure 4 on a flexible soft material.

The other question is, OK, there is difference, and what up ? To determine the mode it is not important. To determine subharmonic or the field strength after determining the shape factor, it is maybe not so bad. The produced error is less than 1 % and the measurement has other error sources, so the conclusion is that it works like it is.

![vibration sensitiveness test](image)

**FIGURE 20.** Magnitude of measured signal during a vibration test.
FIGURE 21. Phase of measured signal during a vibration test.
FIGURE 22. Polar chart of measured signal during a vibration test.

VII. References